NASA Innovative Advanced Concepts

Swarm Flyby Gravimetry

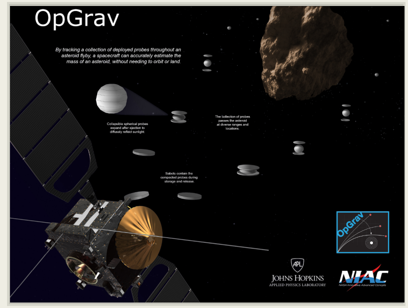
Completed Technology Project (2015 - 2017)

Project Introduction

We propose a method for discerning the gravity fields and sub-surface mass distribution of a solar system small body, without requiring dedicated orbiters or landers. In this concept, a spacecraft releases a swarm of small, low-cost probes during a flyby past an asteroid or comet. By tracking those probes, we can estimate the asteroid's gravity field and infer its underlying composition and porosity. This approach offers a diverse measurement set, equivalent to planning and executing many independent and unique flyby encounters of a single spacecraft. The resulting dataset can yield a global model of the body's mass distribution and reveal unique aspects of the body's interior that are otherwise unobservable. This concept offers the possibility of achieving new scientific measurements that extend our understanding of our solar system, benefit human spaceflight, and support planetary defense. It also represents a practical deep space application of the swarm paradigm that is common in other fields, in that the ensemble of deployed probes enables fundamentally new measurement sets. In Phase I we established a basic feasibility of the concept by simulating a series of asteroid encounters and evaluating the available tracking methods. In Phase II, we intend to address the key remaining risks and concerns by increasing the fidelity of our simulations, evaluating important trades, considering other relevant mission contexts, and prototyping and characterizing the dispenser and probes. These activities will be informed by active engagement with mission science and engineering leadership, with the objective of identifying a path forward for implementation.

Anticipated Benefits

A variety of engineers and scientists, including NIAC fellows, speculate that tiny chip-scale space- craft will constitute meaningful sensor platforms in the coming decades. The NASA Technology 6 Roadmap supports this possibility in the late 2020's. This gravimetry concept represents a mean- ingful step towards that goal. Specifically, this concept benefits from, but does not explicitly require, extremely small probes. Size is relevant because it dictates the number of probes that can be carried for a given payload mass and volume. This research addresses the nontrivial challenge of storing and deploying dozens of compact probes without interfering with the spacecraft bus or adding a risk of future collision. Even for missions unrelated to gravimetry, this research will result in a well-tested dispenser that could be equipped with alternate tiny payloads. For example, the current instantiation of the dispensed containers (\xd2sabots\xd3) could house the Sprites contained in the recent KickSat experiment. Each Sprite consists of solar cells, a radio, and a gyroscope, all integrated onto a single circuit board. With this in mind, it is not unreasonable to see a path forward for deployed magnetometers, bolometers, dust counters, etc.



Artist depiction of Optical Gravimetry, or OpGrav.

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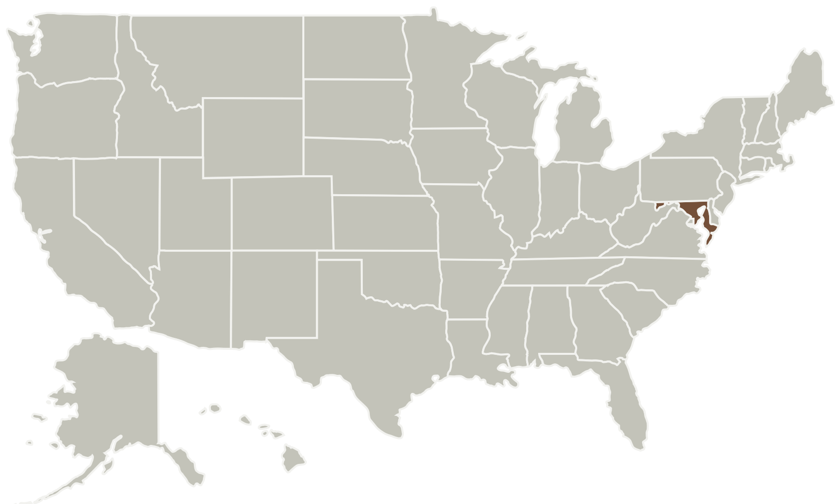

Organizations Performing Work	Role	Type	Location
Johns Hopkins University	Lead Organization	Academia	Baltimore, Maryland

Primary U.S. Work Locations
Maryland

Project Transitions

July 2015: Project Start

Organizational Responsibility

Responsible Mission Directorate:

Space Technology Mission Directorate (STMD)

Lead Organization:

Johns Hopkins University

Responsible Program:

NASA Innovative Advanced Concepts

Project Management

Program Director:

Jason E Derleth

Program Manager:

Eric A Eberly

Principal Investigator:

Justin A Atchison

Co-Investigators:

Andrew Rivkin
Clint T Apland
Ryan H Mitch
Katherine Stambaugh

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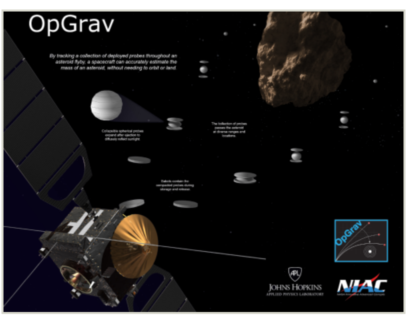
June 2017: Closed out

Closeout Summary: This NASA Innovative Advanced Concept (NIAC) grant has enabled research and development of a method for conducting small body gravimetry from a spacecraft, using relative measurements to a set of deployed test-masses. The test-masses are tracked from a host spacecraft, which dispenses them near to the small body's surface. Thanks to this close proximity, the probes' orbits can be highly perturbed, which yields useful gravimetric measurements. The most readily achievable approach for tracking the probes is to use an optical instrument onboard the spacecraft. The probes then need only be reflective to sunlight. This implementation, called optical gravimetry (OpGrav), has the fewest requirements for the host spacecraft and probes. The results of this study indicate that OpGrav is feasible and offers meaningful improvement over existing methods. Parametric studies suggest roughly an order of magnitude improvement in accuracy or asteroid accessibility (how small an asteroid one can measure) over Earth-based Doppler-only mass estimation. This exponentially expands the number of potential near-Earth objects that one could study, which has implications for planetary defense. As a sample mission, we evaluated OpGrav as an added instrument on a mainbelt asteroid tour mission. In this case, simulations show that OpGrav would increase the number of asteroid mass estimates from 3 of 9 to 7 of 9. That is, OpGrav has sufficient sensitivity to offer utility in missions for which it is not explicitly designed for. We designed and fabricated a prototype hardware implementation for this concept called the Small-body In-situ Multi-probe Mass Estimation Experiment (SIMMEE). This hardware provides a basis for many inputs into the simulations and grounds the models with physical values. The primary design driver for the hardware is a long life, on the order of five years prior to operation, and a need for high pointing accuracy to enable flybys of the smallest objects. The next steps include further hardware testing and extension of the concept to rendezvous cases. We believe that this concept offers planetary scientists a new and relevant means of better understanding small-bodies.

Closeout Link: https://www.nasa.gov/feature/swarm-flyby-gravimetry-optical-gravimetry

Images



Project Image
Artist depiction of Optical Gravimetry, or OpGrav.
(https://techport.nasa.gov/image/102102)

Technology Maturity (TRL)

Start: **2**
Current: **3**
Estimated End: **3**

1	2	3	4	5	6	7	8	9
Applied Research			Development			Demo & Test		

Technology Areas

Primary:

- TX04 Robotic Systems
  └ TX04.2 Mobility
    └ TX04.2.2 Above-Surface Mobility

Target Destination

Outside the Solar System

Links

NASA.gov Feature Article
(https://www.nasa.gov/feature/swarm-flyby-gravimetry-optical-gravimetry)

Project Website:

https://www.nasa.gov/directorates/spacetech/home/index.html